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University of Galway

CT336/CT404
Graphics & Image Processing

Sem 1 (Autumn) 2024-25,
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2nd year M.Sc. (Software Development & Design)
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Visiting students

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Lecture 4: Image Processing

- Introduction

- Point Transformations: A pixel's value is changed without changing its location.

- Geometric Transformations: The location of a pixel is changed from the input to the output image.

- Spatial Filtering (part 1 of 2)

Graphics vs. Image Processing vs. Computer Vision

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1. Graphics:
   - processing and display of images of objects that exist conceptually rather than physically
   - emphasis on the generation of an image from a model of the objects, illumination, etc.
   - emphasis (often) on rendering efficiency for real-time display and/or realism

2. Image Processing:
   - processing and analysis of images of the real world
   - emphasis on the modification of the image

3. Computer Vision/Image Understanding:
   - Computer vision uses image processing and techniques from AI and pattern recognition to recognize and categorize image data and extraction of domain-specific information from images
   - Link to a University's explanation

Image Processing Techniques

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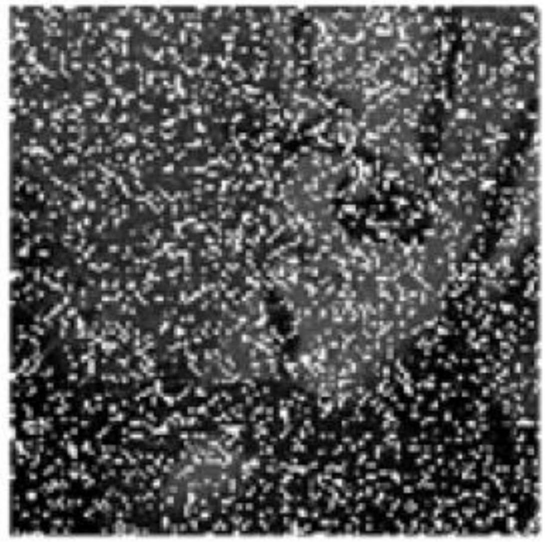
1. Image Enhancement:
   - provide more effective display of data for visual interpretation
   - increase the visual distinction between features in a



(b) Degraded Image (Multiplicative Noise)

2. Image Restoration:
   - correction of geometric distortions
   - Image de-noising
   - Image de-blurring

(

3. Feature Extraction
   - Extraction of useful features e.g. corners, blobs, edges, lines
   - Subtraction of background to extract foreground objects
   - Extraction of image segments, regions of interest

Image denoising using classical statistical approach

Image Processing Applications

- Industrial inspection
- *Document image analysis*
- Traffic monitoring
- Security and surveillance
- *Remote sensing*
- Scientific imaging
- *Medical imaging*
- *Robotics and autonomous systems*
- *Face analysis and biometrics*
- Entertainment

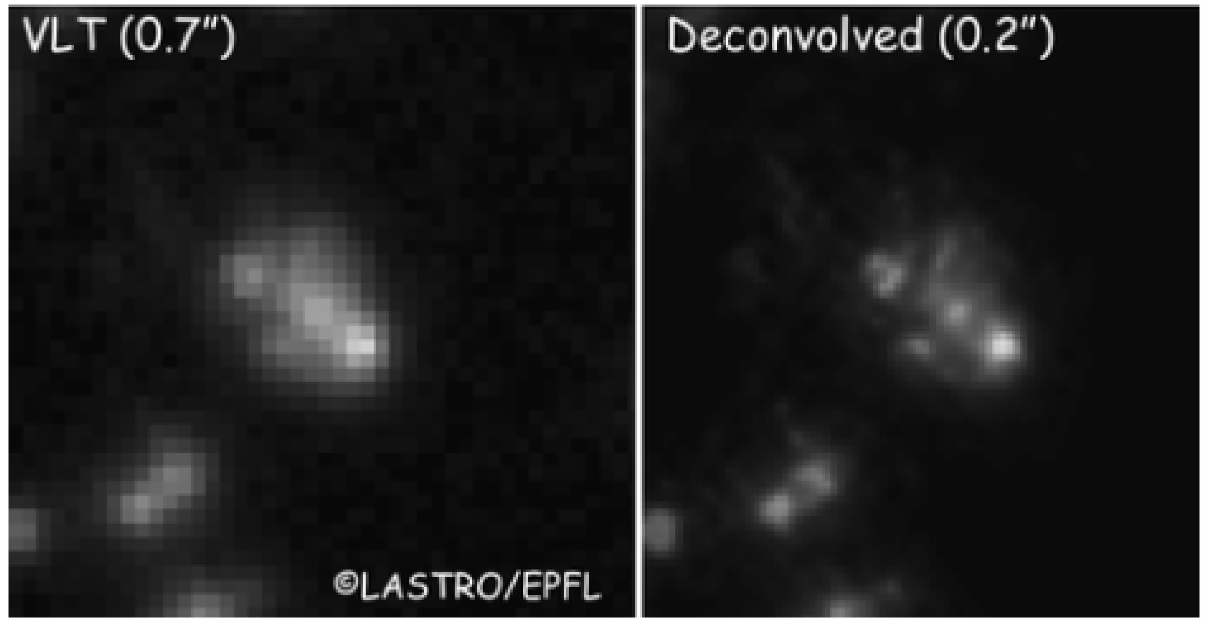


Fig. 1 — from left to right: a) enlargement of an image obtained with the Very Large Telescope (VLT) of the European Southern Observatory (ESO). A small and distant galaxy is seen along with smaller companions, b) image deconvolution of this VLT image, as obtained with our algorithms. The resolution is about 2.5 times better than in the original data, c) the same galaxy seen with the NASA/ESA Hubble Space Telescope, illustrating the reliability of the deconvolution process.

Astronomical image deblurring

reproduced from EPFL, Switzerland website https://www.epfl.ch/labs/lastro/scientific-activities/image-deconvolution/

Digital Images - Bitmaps

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- Bitmaps: grid-based arrays of colour or brightness (greyscale) information
- Pixels (picture elements): the cells of a bitmap
- Depth: bits-per-pixel (bpp)

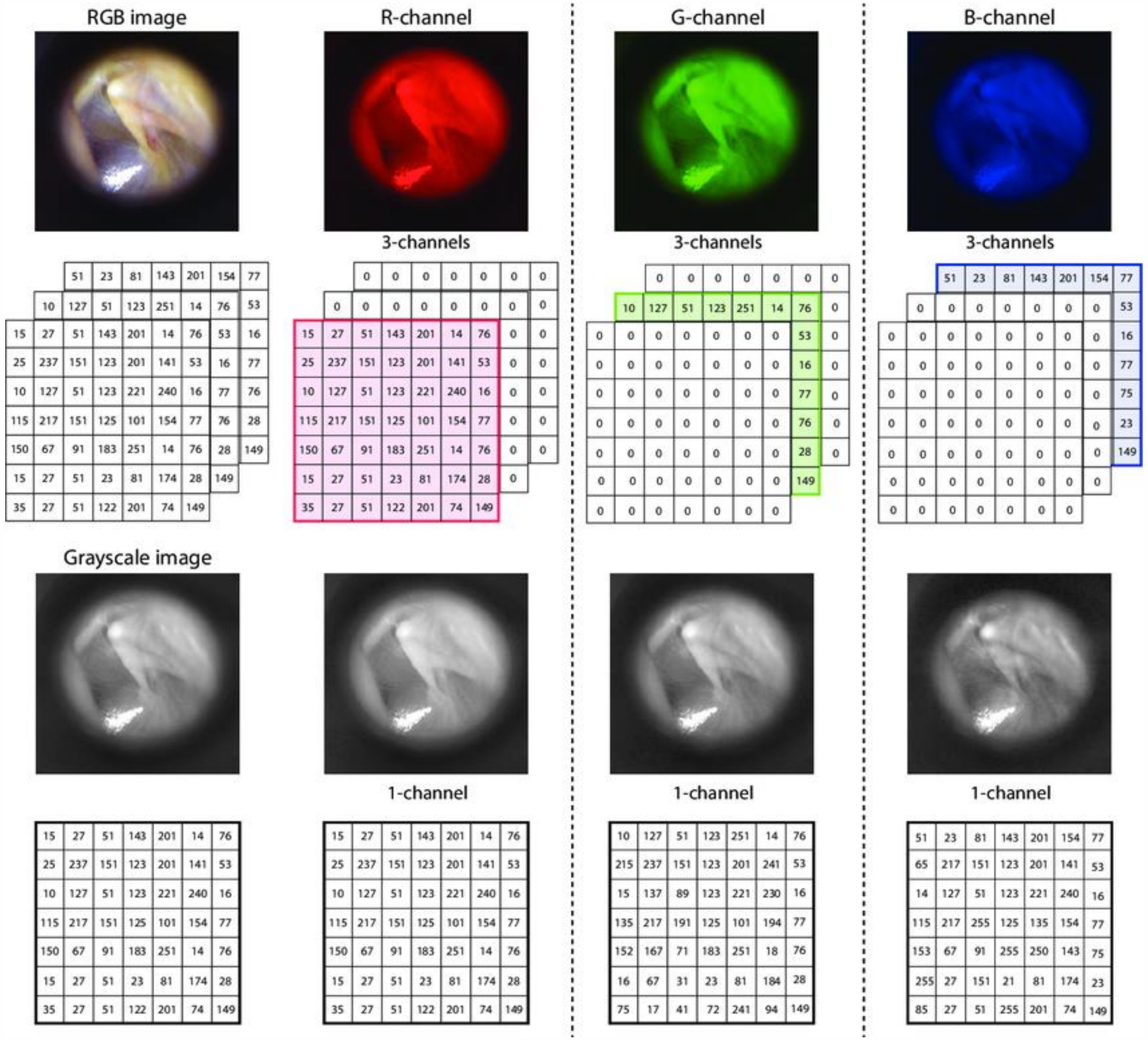
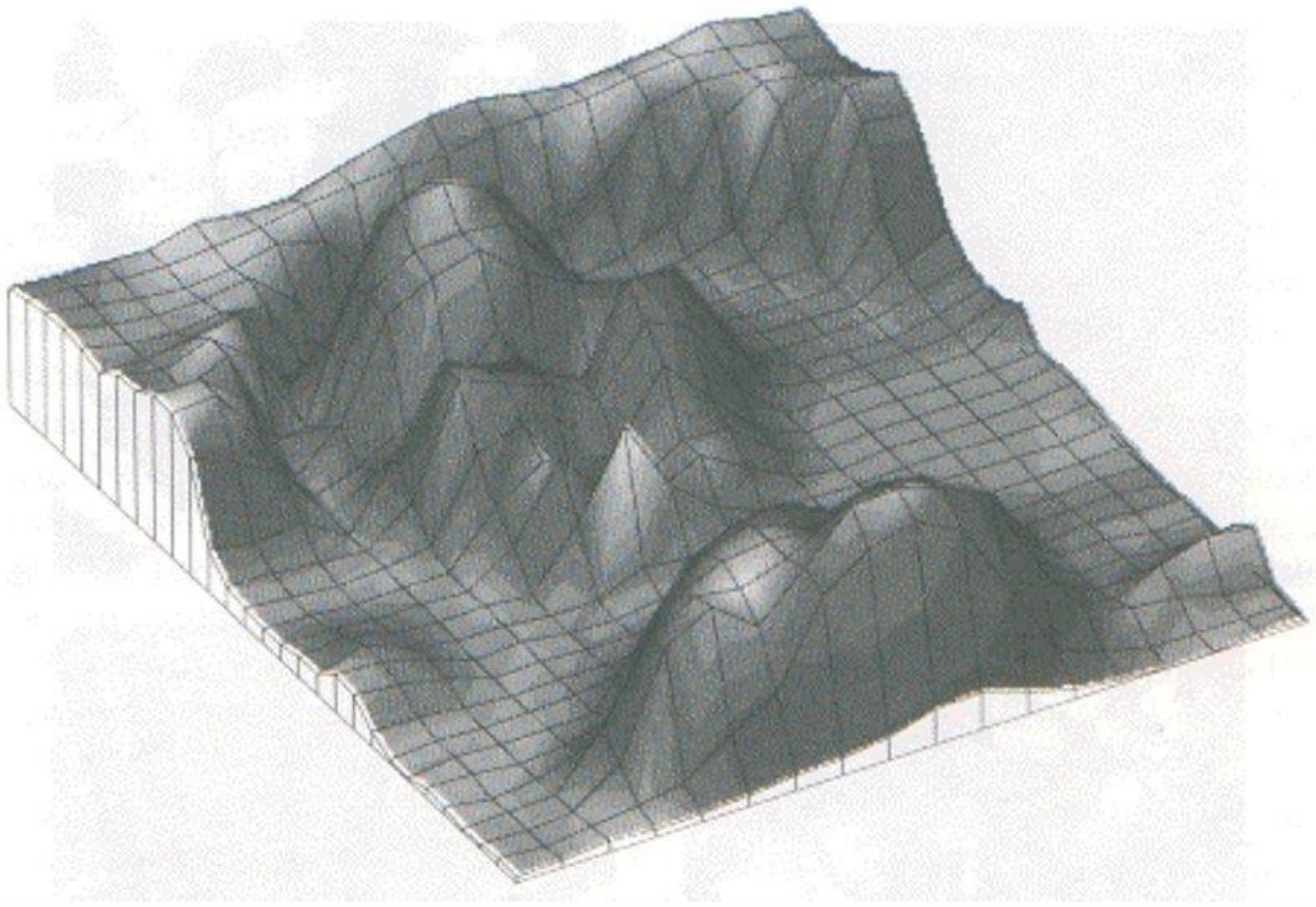
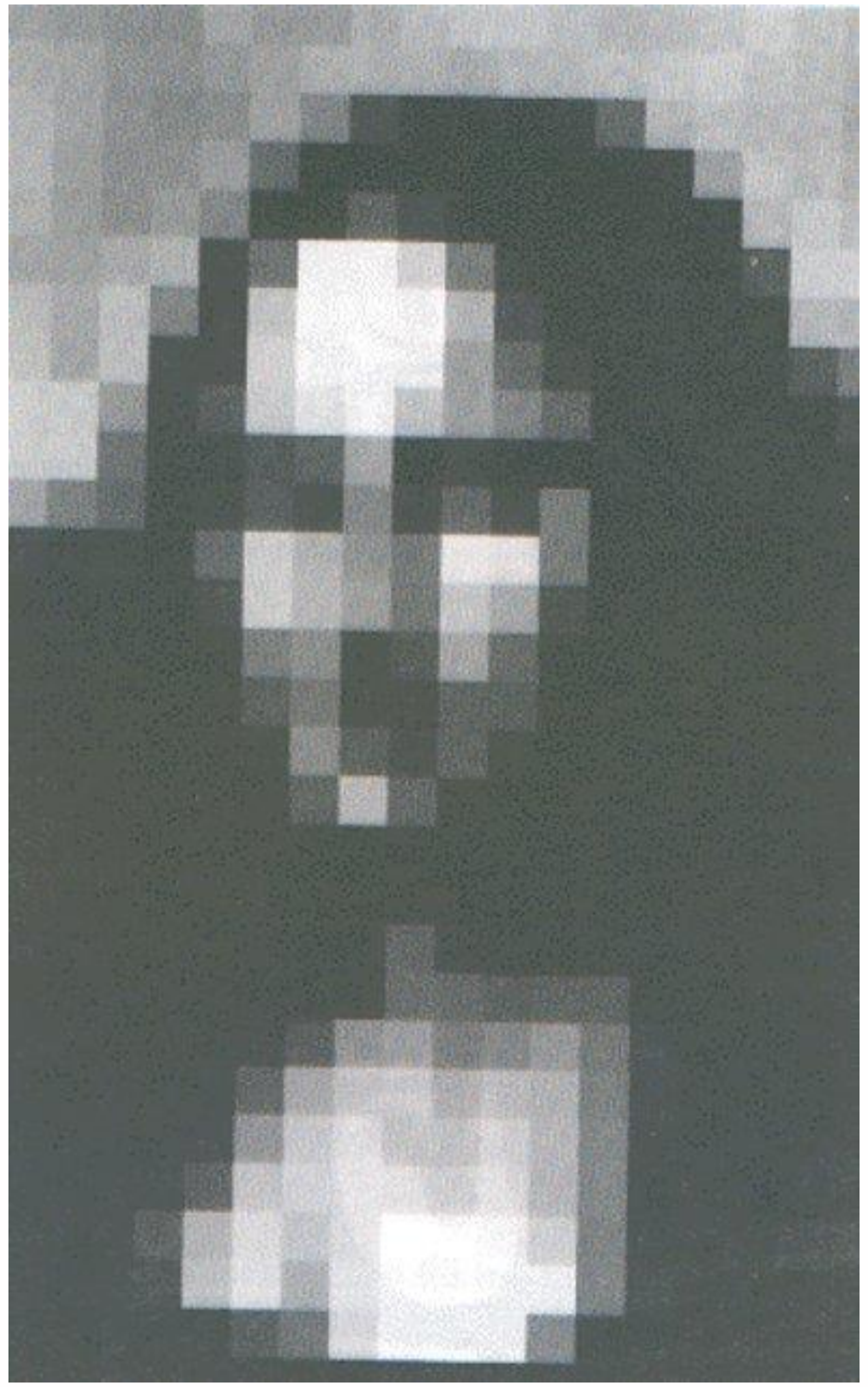


Image reproduced from [1]

[1] Color Dependence Analysis in a CNN-Based Computer-Aided Diagnosis System for Middle and External Ear Diseases - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Matrix-representation-of-a-digital-image-upper-row-from-left-to-right-image-in-the_fig2_359806413 [accessed 11 Sept 2024]





Introduction to OpenCV

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- For high-performance image processing, and to use pre-built library functions, one good choice is Open CV

- Open Source Computer Vision Library (OpenCV) is an open source computer vision and machine learning software library, which is available for Python, C++, Java, Javascript.

- You can also write image processing code directly using Canvas and Javascript
- Or Matlab Image Processing & Computer Vision Toolboxes

- Link to OpenCV-Python Tutorials
- Link to OpenCV-Python Image Processing Module

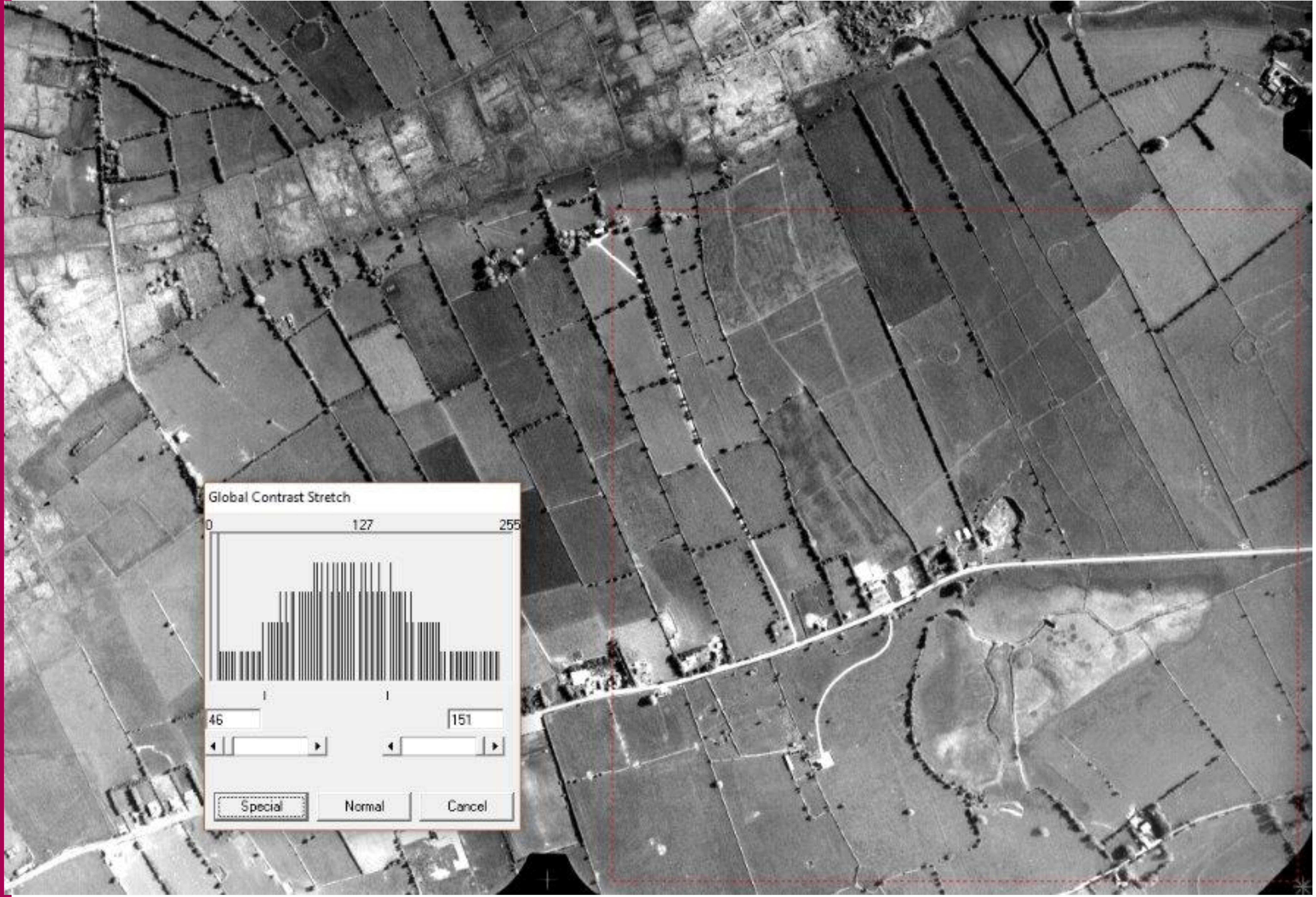
OpenCV

https://opencv.org/

Point Transformations

- Point operations modify the value of each pixel
- **Example: Histogram manipulation**
  - *What is a histogram?*
  - *1. Contrast stretching* spaces out values so that they are more easily distinguishable.
    - *Uniform expansion/ linear stretch (local or global)* assigns as many grey levels to rarely occurring values as to frequently occurring ones.
  - *2. Histogram-equalisation*

A greyscale aerial photo and its greyscale histogram



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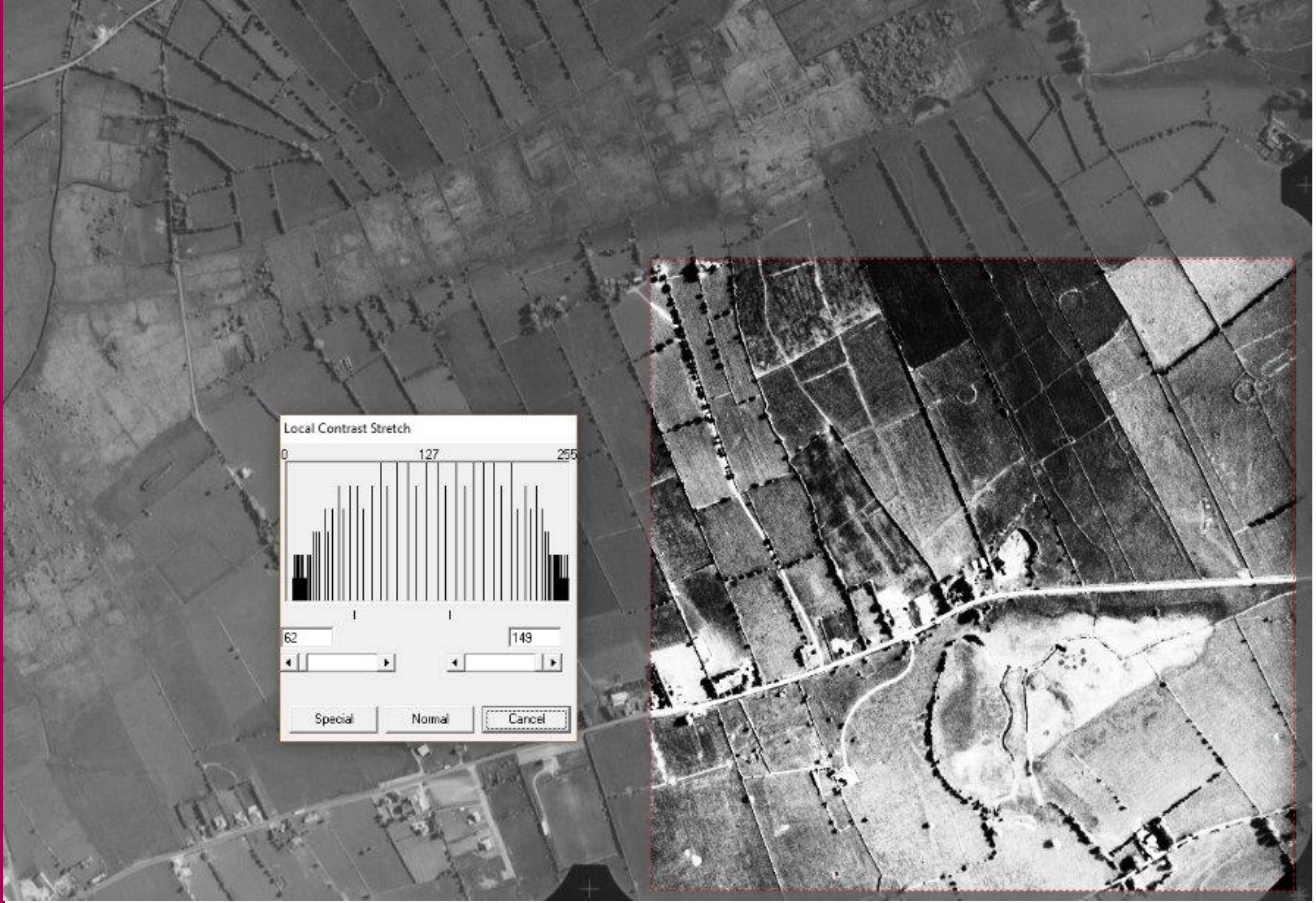
The photo following a global contrast stretch, together with its new greyscale histogram



The original photo, now with a local histogram stretch applied

Point Transformations

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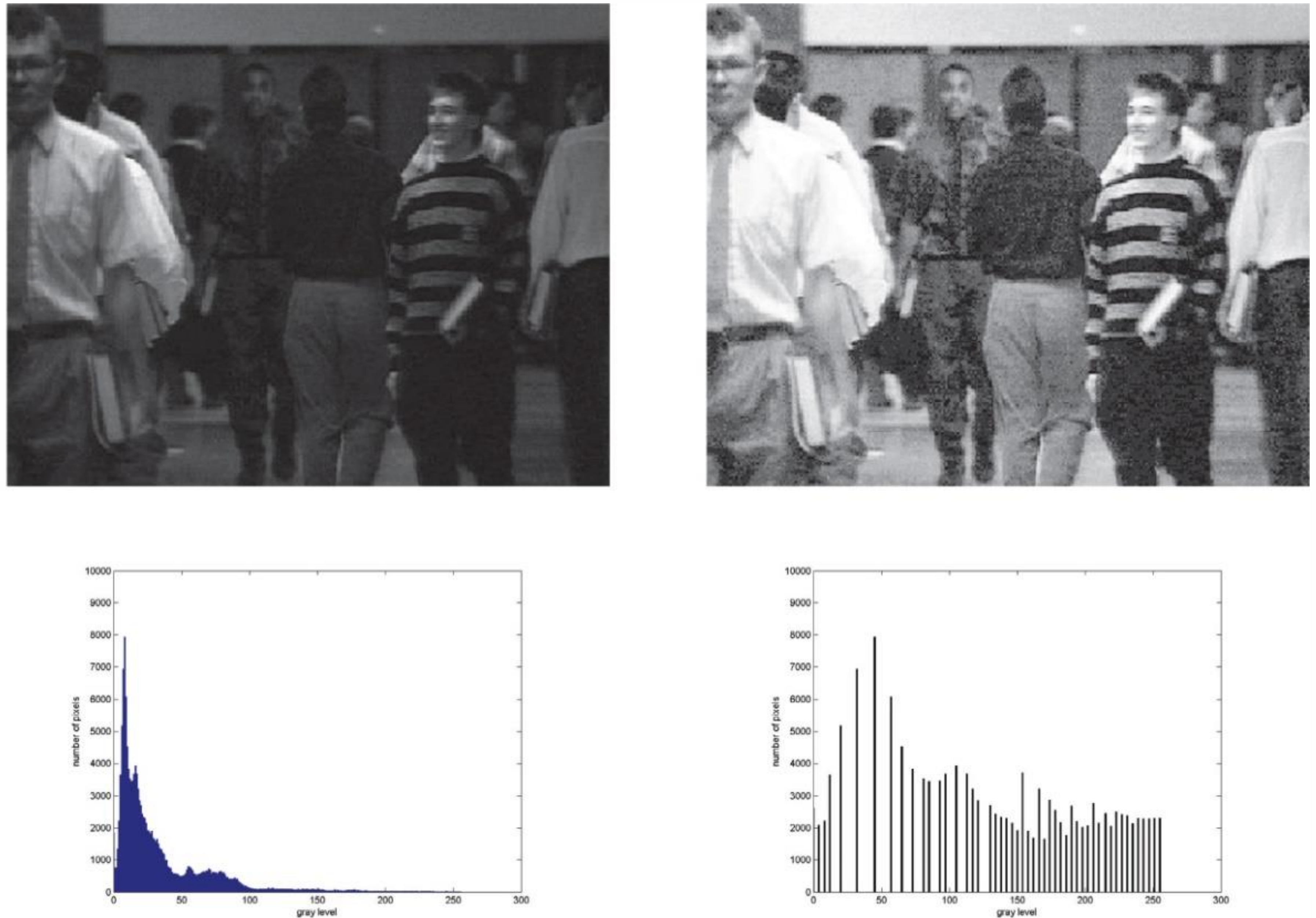
- *Histogram-equalisation:* The aim is to maximise the overall contrast and to produce a nearly uniform (i.e. flat) distribution.
- *Effect?* image values are assigned to new values on the basis of their frequency of occurrence: more display values (and hence more detail) are assigned to the frequently occurring portions of the histogram.

Figure 3.21 The result of histogram equalization applied to an image. The increase in contrast is noticeable. The normalized histogram of the result is much flatter than the original histogram, but it is not completely flat due to discretization effects. Source: Movie *Hoop Dreams*.



Point Transformations

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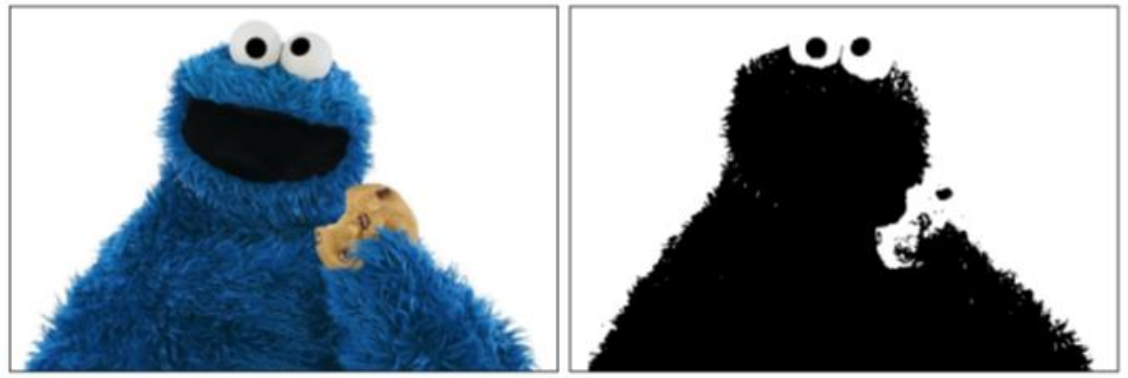
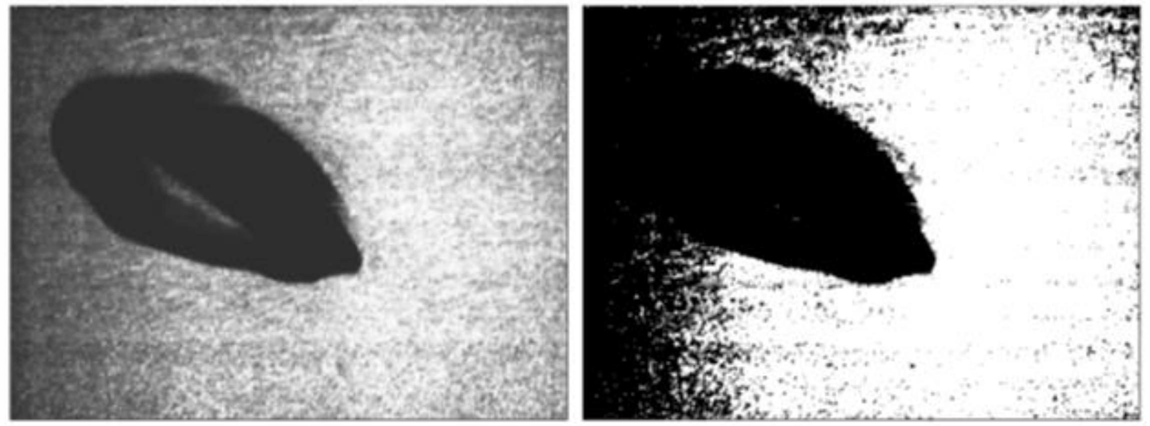
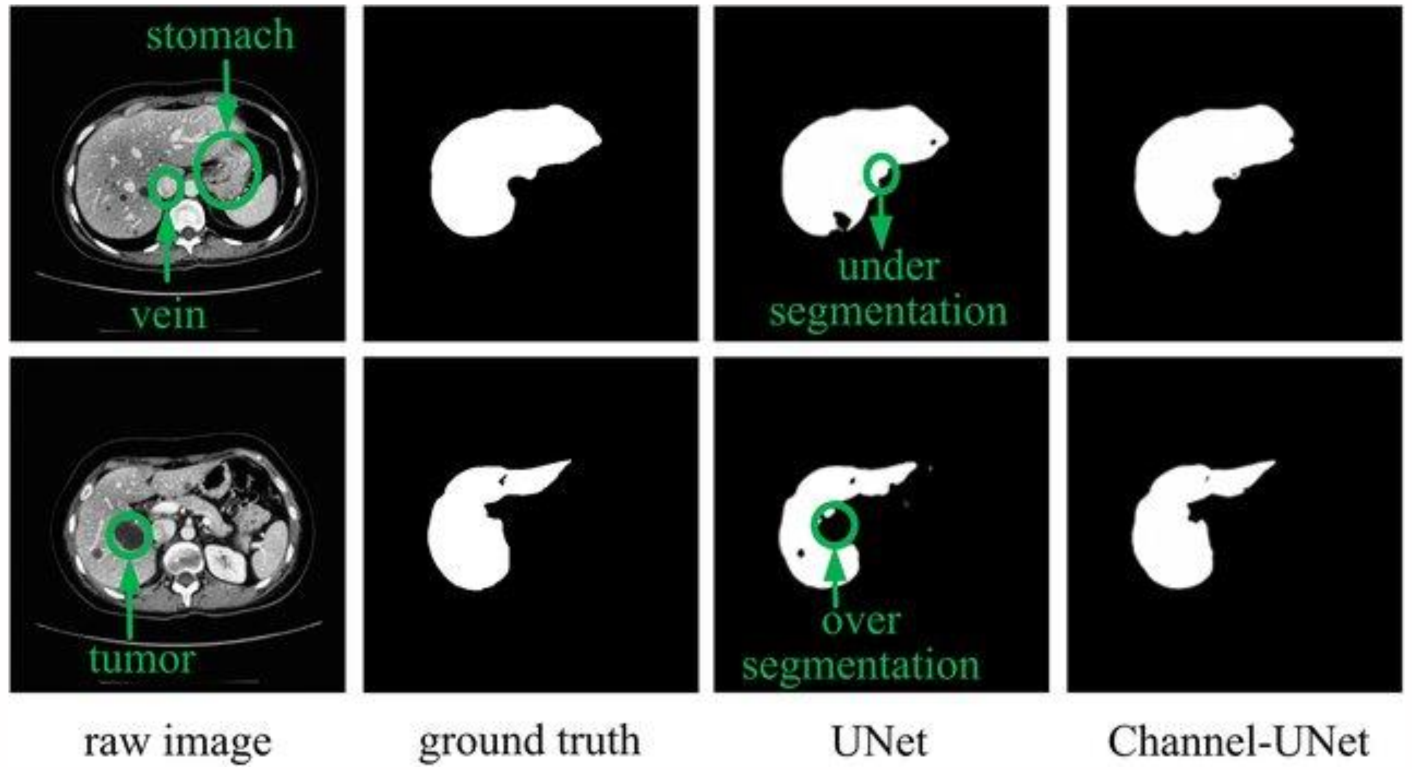
- **Example: Thresholding**
  - A simple segmentation technique that is very useful for separating solid objects from a contrasting background.
  - All pixels above a determined (threshold) grey level are assumed to belong to the object, and all pixels below that level are assumed to be outside the object (or vice versa)
  - The selection of the threshold level is very important. Problems of over-segmentation (false negatives) vs. under-segmentation (false positives)





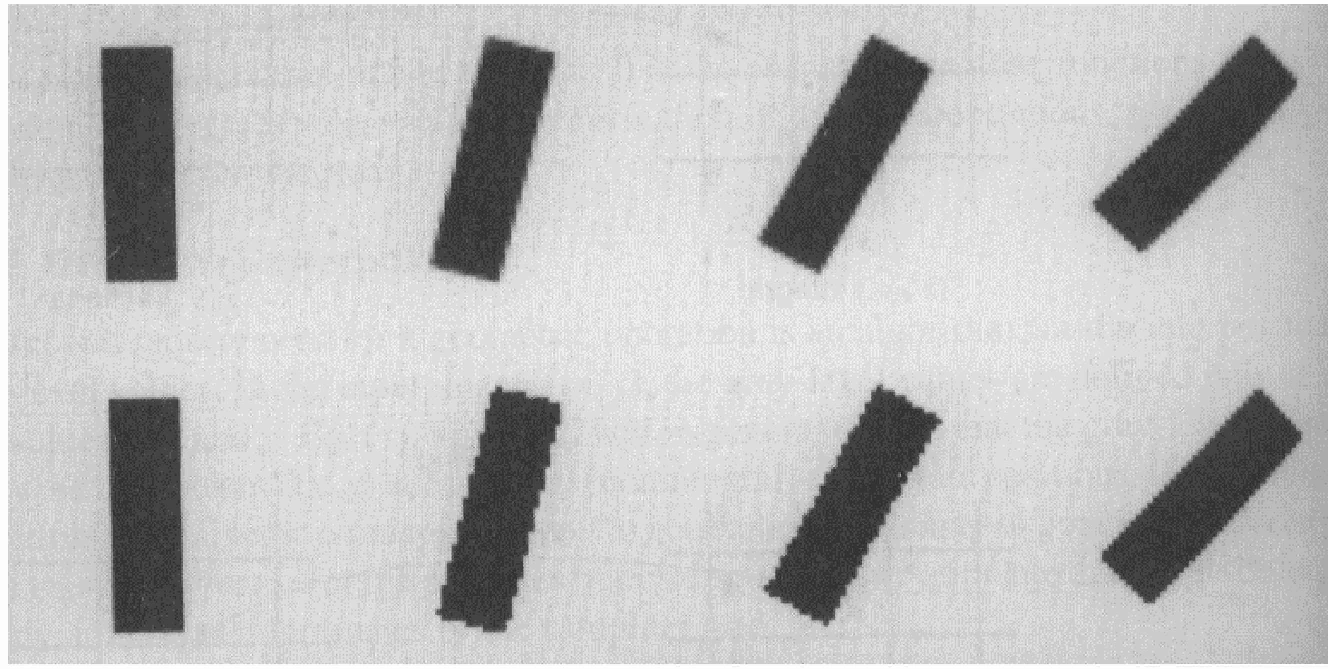


[2] Chen, Yilong & Wang, Kai & Liao, Xiangyun & Qian, Yinling & Wang, Qiong & Yuan, Zhiyong & Heng, Pheng-Ann. (2019). Channel-Unet: A Spatial Channel-Wise Convolutional Neural Network for Liver and Tumors Segmentation. Frontiers in Genetics. 10. 1110. 10.3389/fgene.2019.01110.

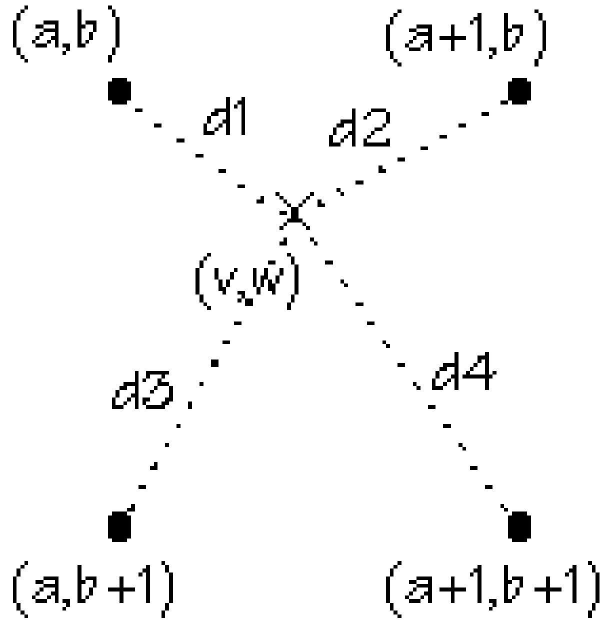
Image source [2]

Geometric Transformations

- **Interpolation:** As a 2D array of values, a digital image can be thought of as a sampling of an underlying continuous function. Interpolation estimates this underlying continuous function by computing pixel values at real-valued coordinates where the estimated continuous function must coincide with the sampled data at the sample points
  - Nearest-neighbour interpolation
  - Bilinear Interpolation: Bilinear interpolation calculates a distance-weighted average of the 4 pixels closest to the target (sub-pixel) position (v,w)
  - Bicubic interpolation: more accurate but costly, where derivatives of the underlying function are also estimated.



Using a rotation operation as an example, we can see how bilinear interpolation is superior to nearest neighbour interpolation



Geometric Transformations

- **Warping: A**rbitrary geometric transformations from real-valued coordinates (x,y) to real-valued coordinates (x',y') where the mapping function f(x,y) specifies the transformation, or warping.

- Some Applications:
  - Image rectification
  - Image registration
  - Map projection
  - Image morphing

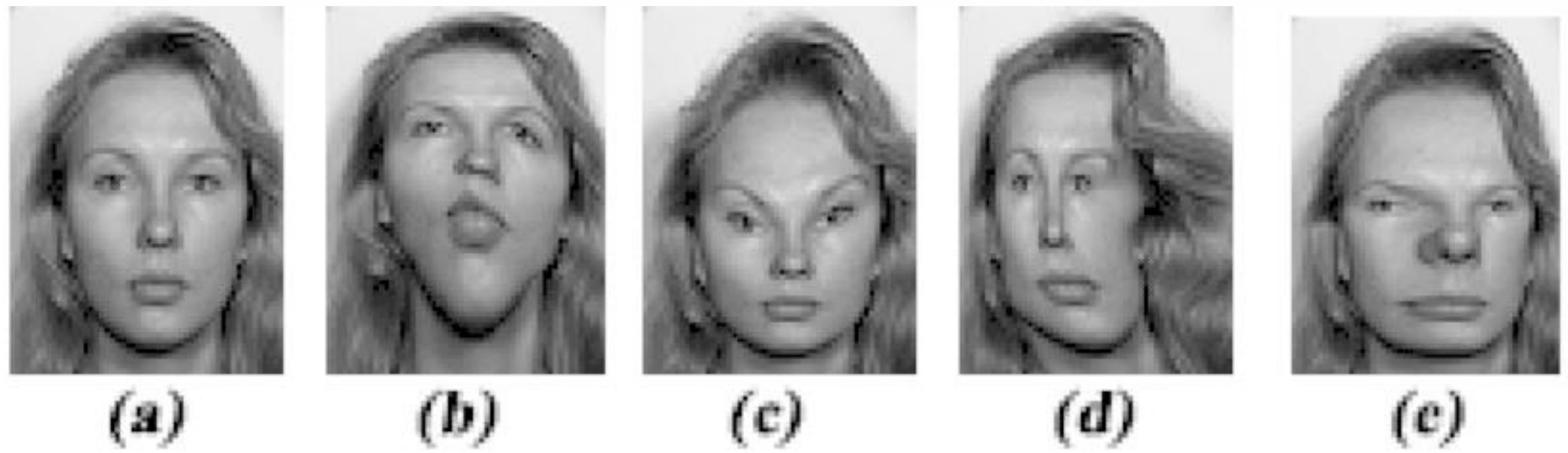


Image source [3]

[3] Karungaru, Stephen & Fukumi, Minoru & Akamatsu, Norio. (2007). Automatic human faces morphing using genetic algorithms based control points selection. International journal of innovative computing, information & control: IJICIC. 3. .

Geometric Transformations

- **Image rectification**
  - Image rectification (part of camera calibration) is a standard approach to geometric correction consisting of displacement values for specified control points in the image.
  - Displacements of non-control points are determined through *interpolation*.
  - e.g. photograph a rectangular grid and then determine the mapping required to move output control points back to known undistorted positions

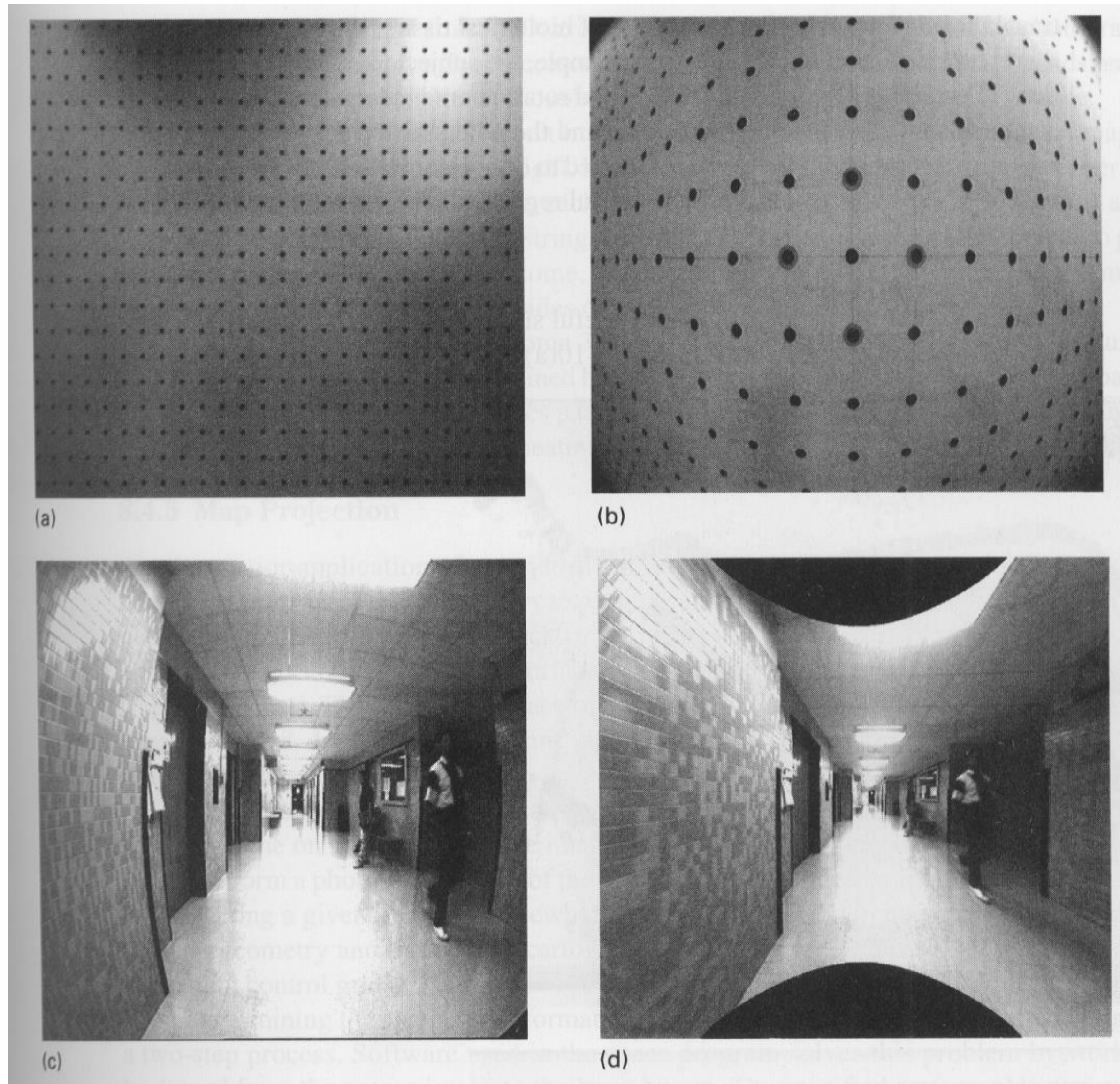
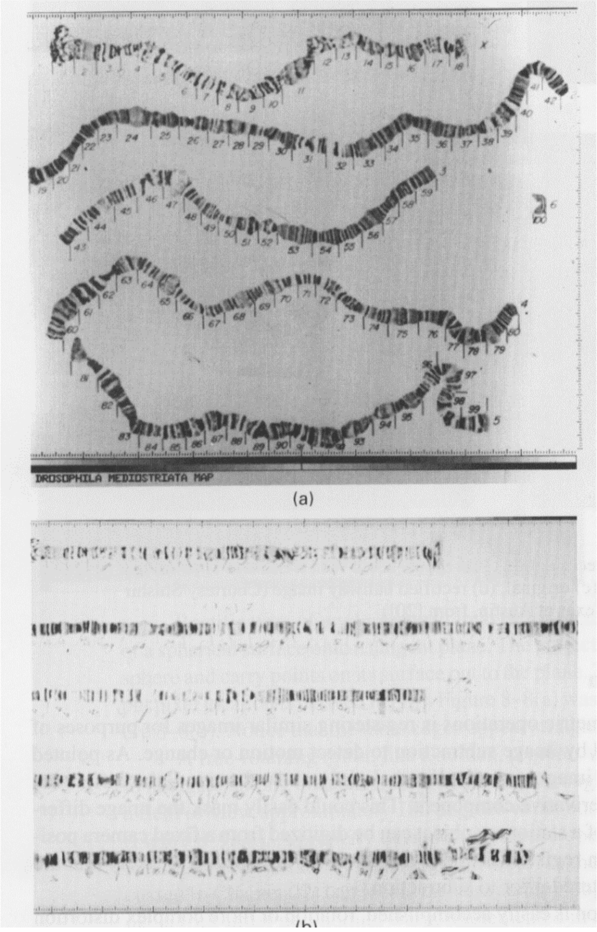


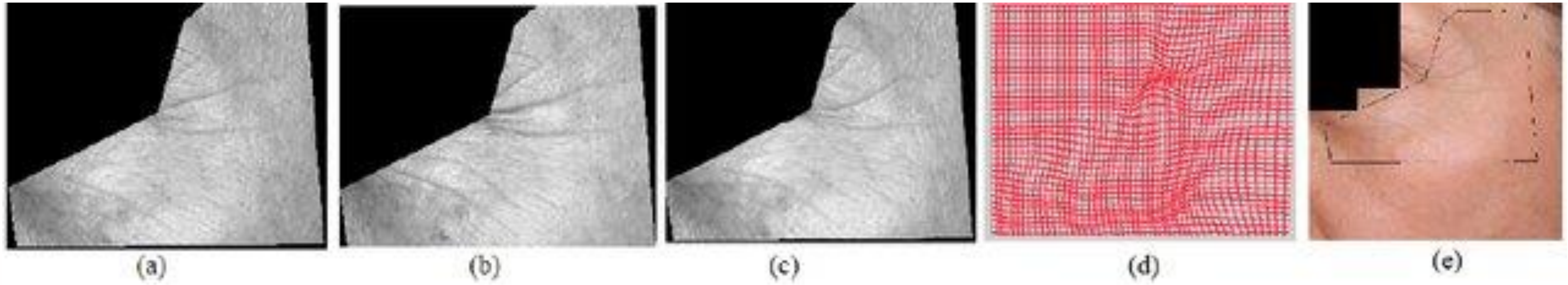
Figure 8–9 Geometric rectification of an image taken with a fish-eye lens: (a) test target, (b) fisheye image; (c) original, (d) rectified hallway image (Courtesy Shishir Shah, The University of Texas at Austin, from [20])

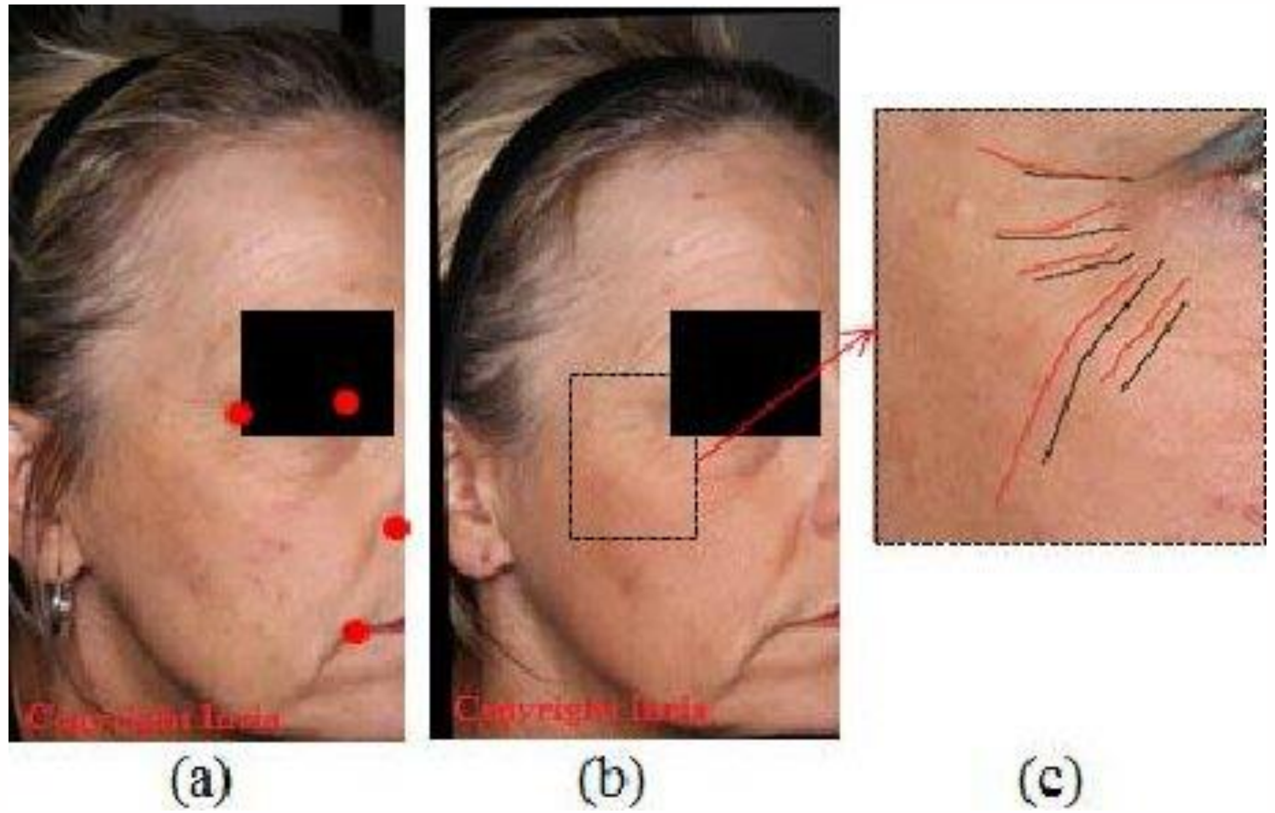
Geometric Transformations

- **(Medical) Image Registration (Application)**
  - The process of transforming different sets of data into one coordinate system
  - Geometric operations applied to images for purposes of comparison, monitoring, measurement
  - Many applications in medical imaging



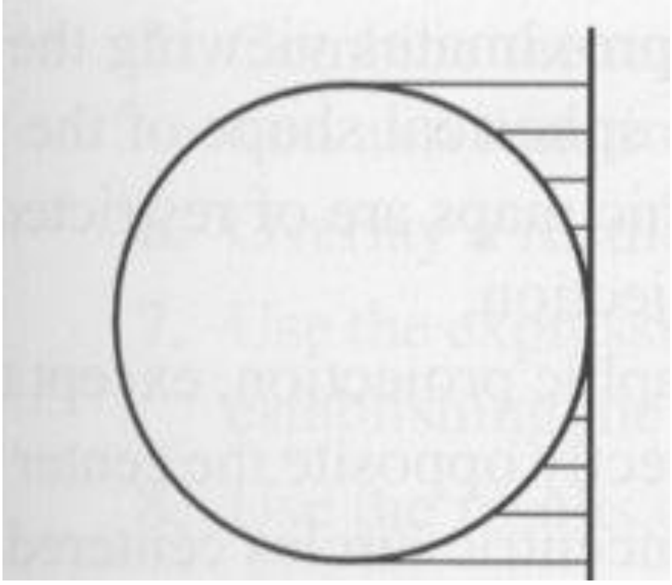
Chromosome images

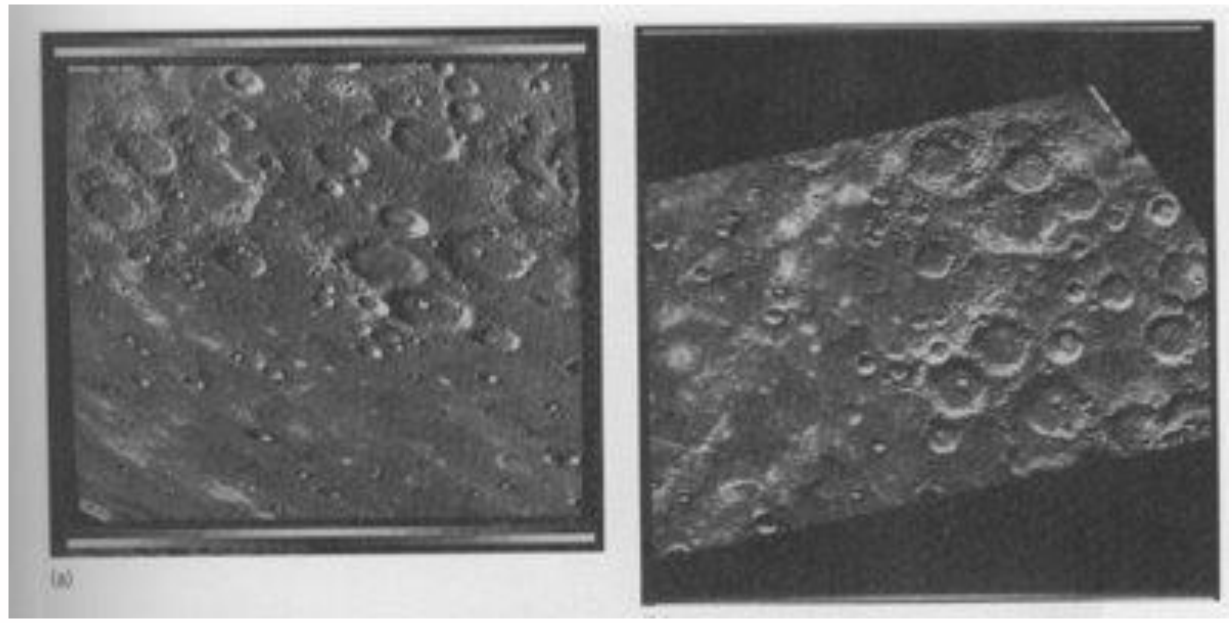




Geometric Transformations

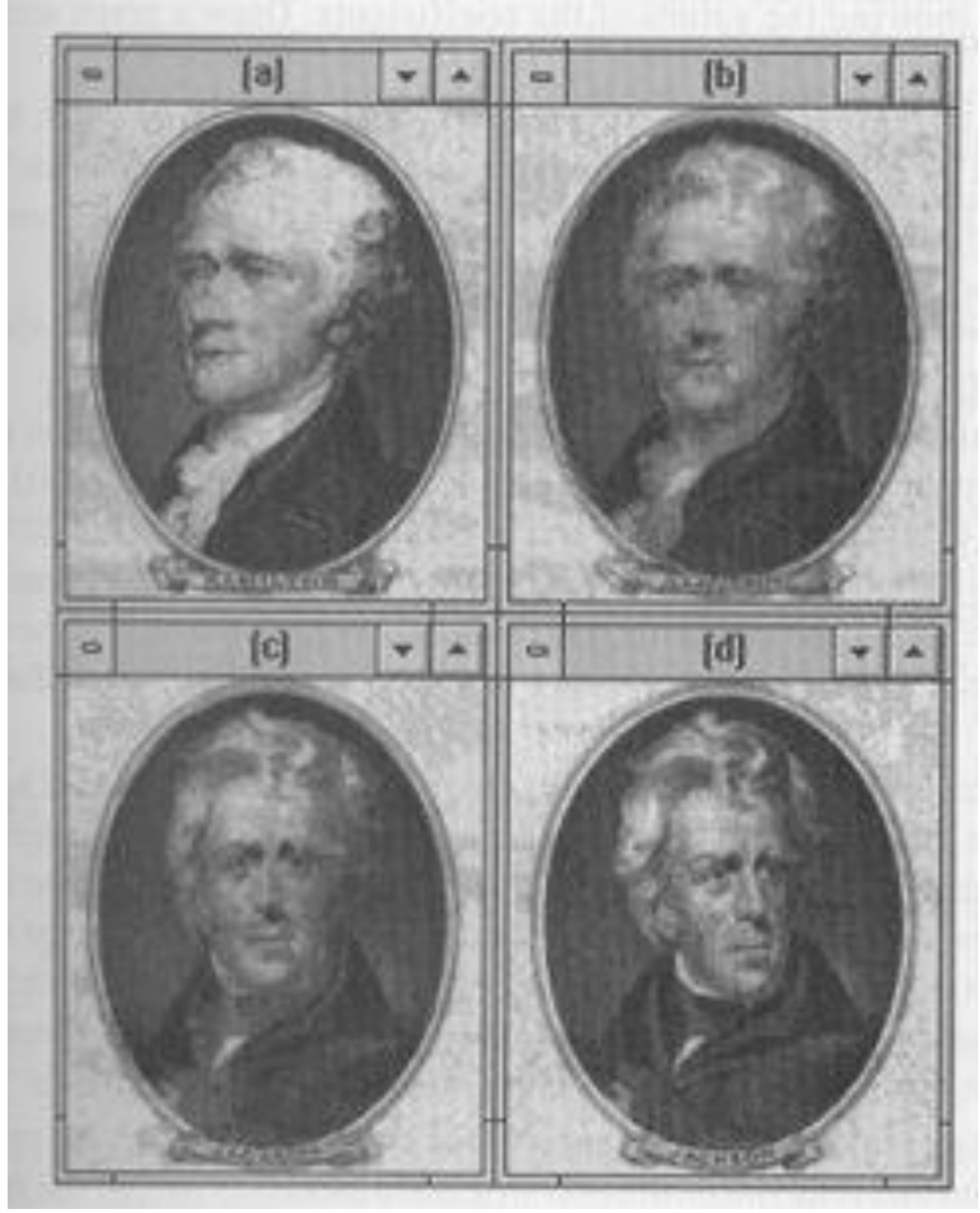
- **Map Projection (Application)**
  - Map projection: aerial or spaceborne images of the surface of a planet may be rectified into photomaps
  - Not only oblique photos but also orthogonal photos require correction, due to shape of surface being imaged
  - Maybe domain knowledge/ assumptions are useful here also? (circular craters)





Geometric Transformations

- **Image Morphing (Application)**
  - Gradually transforms one image into another over a number of animation frames.
  - Involves a dissolve from one image to the other (i.e. gradual change of pixel values), as well as an incremental geometric operation using control points (e.g. nostrils, eyes, chin etc.)
  - An interesting site for image morphing examples



Spatial Filtering (2D-Convolution)

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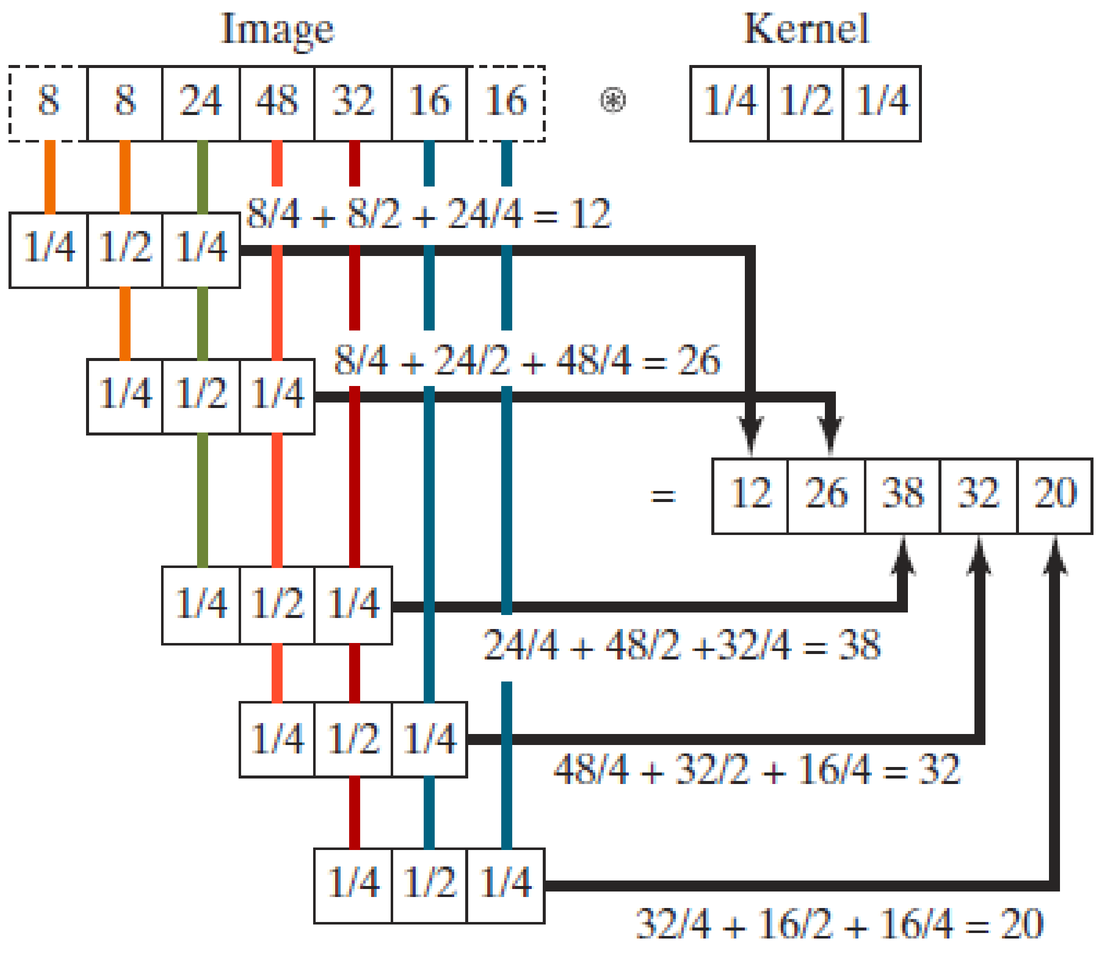
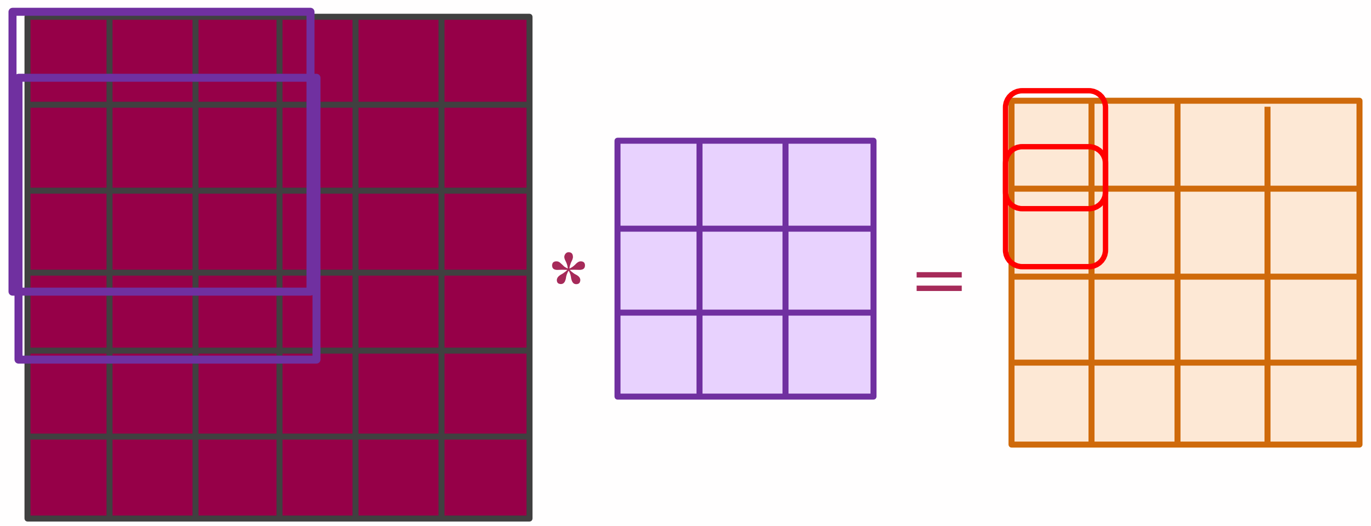
Figure 5.1 An example of 1D convolution.



- A fundamental local operation in image processing
- Used for a variety of tasks, including noise removal, blurring, sharpening, and edge detection.
- Establish a moving window ('kernel') which contains an array of coefficients or weighting factors.
- Move the kernel across the original image, so that it centres on each pixel in turn. Each coefficient in the kernel is multiplied by the value of the pixel below it, and the addition of each of these values determines the value of the pixel in the output image corresponding to the pixel in the centre of the kernel.
- *Why is it called filtering?*



Spatial Filtering (2D-Convolution)

- **Smoothing kernels:** perform an averaging of the values in a local neighborhood and therefore reduce the effects of noise.

- Such kernels are often used as the first stage of preprocessing an image that has been corrupted by noise, in order to restore the original image.

- **Differentiating kernels**: accentuate the places where the signal is changing rapidly in value.
- used to extract useful information from images, such as the boundaries of objects, for purposes such as object detection.

Spatial Filtering – Smoothing filters

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Discrete Approximation of Isotropic Gaussian filter 3x3, 5x5, 7x7

Box (Average) Filter

1/9

1	1	1
1	1	1
1	1	1

1/16

1	2	1
2	4	2
1	2	1

1/273

1	4	7	4	1
4	16	26	16	4
7	26	41	26	7
4	16	26	16	4
1	4	7	4	1

1/1003

0	0	1	2	1	0	0
0	3	13	22	13	3	0
1	13	59	97	59	13	1
2	22	97	159	97	22	2
1	13	59	97	59	13	1
0	3	13	22	13	3	0
0	0	1	2	1	0	0

Spatial Filtering – Smoothing filters

Original

Box (Average) Filter 3x3

Gaussian filter: 3x3, sigma 0.5

7x7, sigma 0.5

7x7, sigma 1.5

Next Time

- Continue with Spatial Filtering
- Filtering in frequency domain – *An eye-opener?*

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Thank *you*